Imprints from idea origin on innovation and the development environment

Isabel Maria Bodas Freitas

Grenoble Ecole de Management, Univ Grenoble Alpes ComUE, 12 Rue Pierre Sémard, 38000 Grenoble, France
isabel-maria.bodas-freitas@grenoble-em.com

Cornelia Lawson

School of Management, University of Bath, Quarry Rd, Bath BA2 7AY, UK
c.lawson@bath.ac.uk

Abstract

This study builds on the evolutionary and organization literatures to explore how the nature of innovation outcomes was influenced by the innovation's original idea and the environment in which it was developed. We use data from a survey of inventors on the development processes of three types of innovations: market success innovations, technologically novel innovations, and innovations that are both technologically novel and of market success. Our results suggest that the environment in which the project is developed erodes the effect of the original knowledge sources on the innovation outcome. Specifically, a stronger imprinting effect of knowledge sources is found for independent inventors, while ideas are more likely to be eroded in projects undertaken by inventors at technology leader firms.

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Introduction

Innovations can differ substantially in their scientific and commercial importance. While some innovations are able to utilize advanced technologies and contribute to scientific advancement, others are generating greater sales and thus contribute to a greater extent to the revenue of the firm (Riggs and von Hippel, 1994; Zhou et al., 2005; Kaplan and Vakili, 2015). The prior literature has linked these differences in innovation outcomes to differences in the needs that a firm's workforce serve, the incentives they are exposed to, and the knowledge and ideas they recombine (Kogut and Zander, 1992; Rodan and Galunic, 2004; Golder et al., 2009; Baba and Walsh, 2010; Arts and Veugelers, 2015; Capaldo et al., 2017). This discussion, however, does not determine whether we would expect similar types of original ideas for innovation to result in the same types of innovation outcome when they are pursued in different development contexts. Understanding this interaction between original idea and development environment is important as it may help us to understand how different innovations may be fostered and, consequently, help firms understand how to incentivize their workforce.

Innovation is often understood as the outcome of the interplay between *variety generation* and *selection* involving a cumulative learning process (Nelson and Winter, 1975; Dosi, 1982; Nonaka et al., 2000; Andrianni and Cattani, 2016; Ching, 2016; Garud et al., 2016). Variety generation emphasizes the innovation's *origin,* understood as the founding conditions that influence the nature of the innovation, as their imprints are said to persist across the innovation development process (Phene, et al., 2006; von Hippel et al., 1999). Yet, a technology may offer a variety of innovation development opportunities, and the 'distinct resource environment' (Cattani, 2006: 288) in which an idea is developed creates specific '*selection forces* ' (Cattani 2006: 286) that may erode or reinforce the imprints of the original idea on the innovation outcomes. Despite acknowledging the importance of different forces in the development process little systematic work has tried to understand how such forces interact.

This study contributes to answering this question by examining the development processes behind three types of industrial innovations, using survey data of Italian inventors: market success innovations (proxied using inventions with the greatest market value), technologically novel innovations (proxied using inventions with the highest contribution from university knowledge), and innovations that are both technologically novel and market success innovation. We investigate whether and how different development environments to which inventors are exposed – independent (self-employed) vs. corporate and technology-leader firms vs. technology-follower firms – interact with different knowledge sources at the origin of the innovation project – firm R&D, firm operational and commercial activities, and university knowledge – to direct the nature of the resulting innovation process. Our empirical setting has several advantages that aid our analysis. By having information on up to two innovations per inventor, we are able to control for several personal and project characteristics that may affect knowledge origin and/or innovation outputs (Felin and Hesterly, 2007; Singh and Fleming, 2010). Further, while it can be argued that certain knowledge sources at the origin of the innovation project may be more likely to be chosen by inventors operating in specific environments (Golish et al., 2008), in our sample, knowledge sources and development environment are statistically independent. This permits us to separate the three main phases in the imprinting process.

Our results show that ideas based on interactions with other market actors in the pursuit of operational and commercial activities have a stronger imprinting effect on innovation outcomes than ideas based on firm R&D activities or from university research. The imprinting effect of ideas appears to be stronger for innovations developed by independent/self-employed inventors, followed by inventors working in technology follower firms. Instead, they are more likely to be eroded in projects undertaken by inventors working in technology leader firm.

Our results and discussion make two main contributions which can inform future research. First, this study contributes to the evolutionary economics - in particular to the speciation - literature, which has long argued that a new technology could emerge if an existing technology is applied to a new domain (Levinthal, 1998). It contributes by showing that the '*selection forces*' (Cattani, p.286) to which inventors are exposed during the development of the original idea guide inventors' development efforts towards different types of innovative outcomes. Specifically, our results show that inventors in environments that maintain a large pool of resources and knowledge may erode the imprinting effect of the original idea on the innovation outcome. Still, the strength of these *'selection forces'* created by the development environment seems to depend also on the type of knowledge source that informed the project idea.

Second, this study can contribute to the imprinting literature which builds on the Stinchcombe (1965) claim that "characteristics of an entity shaped during a sensitive moment of its existence can persist […] in spite of subsequent environmental changes" (Simsek et al., 2015, p.289). Recently this literature has stressed the importance of refining the conceptualization (and consequently the identification) of imprinting as a multi-level process so that imprinting formation, transformation and its manifestation in outcomes may be distinguished (Marquis and Tilcsik, 2013; Simsek et al., 2015). Our study contributes by showing that the persistence of knowledge source imprints is associated with the type of knowledge source at the origin, as well as the environment in which inventors are developing the innovation idea.

The paper is organized as follow. Next, we develop a framework and derive hypotheses to guide our analysis. Then, we present the methodology and data used in this study, and report the results. We conclude the paper discussing the results, their implications and limitations.

Analytical framework

Innovations are often categorized according to their technological and scientific importance and their commercial importance (Riggs and von Hippel, 1994; Kaplan and Vakili, 2015). More than differing in the product development stage that they reach, they seem to differ in terms of the knowledge and resources they recombine, as well as the degree of social acceptance and need in markets and in society for these innovations (Kogut and Zander, 1992; Rodan and Galunic, 2004; Golder et al., 2009; Baba and Walsh, 2010; Arts and Veugelers, 2015). In the extensive innovation literature, it is however still not clear whether the same type of innovation output can originate from similar types of knowledge sources when they are pursued in different contexts. To answer this question, we bridge evolutionary economics and organizational inspired approaches and develop a framework to examine how the main knowledge source on which the original idea for innovation is based and the environment in which this idea is developed interact to influence the nature of the innovation. Contributions in evolutionary economics have largely focused on the *selection* processes underlying innovation development [1], while organization theory has inspired empirical analyses of how firms' organizational capabilities and structures help to explain differences in firms' strategies and performances, i.e. imprinting effects. [2] Combining insights from both literatures, we look at the processes determining innovation outcomes afresh. In our framework (see Figure 1), we understand an idea as a source of opportunities for innovation development and conceptualize innovation as the result of the development of an original idea in a specific environment.

[Insert Figure 1 about here]

We distinguish three different types of industrial innovations: market success innovation, technologically novel innovation and innovations that are both technologically novel and of market success. The different stimuli and resources to which inventors have been exposed during the idea-generation (in terms of knowledge sources they rely on) and idea-development processes (in terms of access to resources and possibility to pursue certain development paths) can be considered as endogenous to the innovation process. Inventors develop projects based on ideas that originate from knowledge sources internal or external to the firm (Cohen and Levinthal, 1990; Ahuja and Lampert, 2001; Cassiman and Veugelers, 2006) and, when external, from universities (and other public research) or from firms' operational activities (Cohen et al., 2002; Laursen and Salter, 2006; Giuri et al. 2007). Here, we thus consider three main groups of knowledge sources which have been shown to influence innovation outcomes: firm R&D activities, firm operational and commercial activities, and university research (von Hippel et al., 1999; Phene, et al., 2006; Golish et al., 2008; Kornish and Ulrich, 2014; Arts and Veugelers, 2015).

However, there is no one-to-one relationship between the origin of the innovative idea, and the nature of innovations developed, as each idea may permit and inspire a variety of development paths (Gibbons and Johnston, 1974; Basalla, 1988;, Shane, 2000; Garud et al., 2013; Tuertscher et al., 2014). The environment to which inventors are exposed when developing the original idea into an innovation, further frames individuals' decisions regarding specific development paths and determines the possibilities and opportunities to access relevant resources (Burgelman 1994; von Hippel et al., 1999; Nonaka et al., 2000; Zhou et al., 2005).

A particularly relevant distinction in terms of the development environment, largely used in the creativity and entrepreneurship literatures, is whether inventors are corporate employees or independents (Markman et al., 2002; Corbett and Hmieleski, 2007; Lettl et al., 2009). A second important distinction refers to the corporate environment, to strategies for innovation within firms, and consequently the resources, incentives and skills available; some of which are more conducive to innovation (Amabile, 1988; Dahlin et al., 2004; Lettl et al., 2009). Specifically, technological leader and follower firms develop organizational, market and technological capabilities that lead them to pursue different market and technological strategies (Lieberman and Montgomery, 1988; Dos Santos and Peffers, 1995; Giachetti et al., 2017). Hence, we distinguish the following development environments: Independent/self-employed and corporate inventors; and amongst corporate inventors those employed at technological leader organizations; and those at technological follower organizations. Figure 1 summarizes the analytical framework that builds the basis for our literature review and empirical analysis.

Imprints from the knowledge origin on innovation outcome and the contingent effect of the development environment

The main objective of industrial R&D activities is to sustain current and future market needs of the firm. These activities focus on the search for knowledge and proof of concept that can be used as technological inputs for developing new or improved products as well as supporting the production of high quality products (Cohen and Levinthal, 1990; Tripsas and Gavetti, 2000; Ahuja and Lampert, 2001). Even when investing in basic research, firm R&D activities focus on applicability, i.e. on the development of commercially viable products and technologies that allow the firm to improve their market position and their level of value appropriation in the market (Cohen and Levinthal, 1990; Rosenberg and Nelson, 1994;

von Hippel et al, 1999; Nonaka et al, 2000). Thus, when inventors use technological knowledge developed by the company's internal activities as main input for their activity, they are likely to create and innovate upon products and technologies that are compatible with the firm's existing knowledge and assets, that fit their mainstream customers (Tripsas 1997; von Hippel et al., 1999; Christensen and Bower, 1996; Bergek et al., 2013; Maslach, 2016).

Knowledge developed in (or co-developed with) universities and public research organizations (PROs) may also be of relevance to industrial innovation (Mansfield 1991; Laursen and Salter, 2006). It can inspire the exploration of technological developments and support the resolution of problems that can lead to technological but also to market innovations (Rosenberg and Nelson, 1994; Hall et al., 2000). When inventors use knowledge developed or co-developed by university researchers as the main knowledge source for their activity, they may be encouraged to follow new search and recombination strategies, and consequently be more likely to obtain a technologically novel innovation (Rosenberg and Nelson, 1994; Fleming and Sorenson, 2004).

However, according to Cohen et al. (2002), the majority of R&D projects leading to innovations tend to be based on ideas resulting from firm's operational and commercial activities. Interactions with other market actors, in particular with customers and suppliers, may provide an opportunity for the transfer of sticky information regarding the customers' existing and potential demands, technological opportunities, or expectations for new or improved products (von Hippel, 1986; 1994; Clark, 1989; Lilien et al., 2002; Chatterji and Fabrizio, 2012). This information and knowledge collected via the operational and commercial activities of the firm may then be used by inventors as inputs into their activity. Being compatible with existing or potential needs of mainstream customers, these sources may inspire inventors to search for improvements that are likely to become a market success rather than for product and technological alternatives addressing emerging markets (Slater and Narver, 1995; Im and Workman, 2004; Zhou et al., 2005).

Recent literature also suggests that ideas resulting from firm operations, being closer to the firm's existing markets than other knowledge sources, may be closer aligned to new market needs (Cohen et al., 2002;

von Hippel and von Krogh, 2016). Hence, ideas provided by firm operations may require adaptation and development but less recombination before they can be brought to the market (von Hippel and von Krogh, 2016; Andriani et al., 2017). Instead, ideas from firm R&D activities or from university partners more often result from the adaptation or exaptation of a solution to a specific problem relevant to the value creation strategy of the firm, requiring more recombination (Felin and Zenger, 2016; Andriani et al., 2017). Our first hypothesis thus states that:

> *H1: Ideas originating from knowledge closer to operational and commercial activities of the firm are more likely to imprint the innovation outcomes than ideas originating from university knowledge sources or firm R&D.*

However, several differences have been identified in the behavior and performance of inventors exposed to different development environments. Corporate and independent inventors are likely to have different believes and behaviors regarding their job (Mitchell et al., 2000; Corbett and Hmieleski, 2007), and their competence in organizing, executing and achieving expected outcomes (Markmann et al., 2002). These differences may, in turn, influence their motivations, persistence and level of efforts in carrying on their innovative projects as well as the problem-solving methods used (Wood and Bandura, 1989; Corbett and Hmieleski, 2007).

Corporate inventors have been found to have a greater ability to combine diverse types of knowledge, as they can more easily access the knowledge, resources, and complementary assets of the organizations which pay their wages (Lettl et al., 2009). However, the complementary assets and managerial systems of organizations often become captive of their current customers (Leonard-Barton, 1992; Tripsas, 1997; Christensen and Bower, 1996), and may develop organizational structures that can create rigidities to the exploration of promising but radically different technological solutions and products for markets that do not yet exist (Tripsas and Gavetti, 2000; Bergek et al., 2013). Even if corporate inventors develop prototypes of new disruptive technologies, the company tends, for a period, to resist cannibalizing their own markets and products (Agarwal et al 2004; Klepper and Sleeper, 2005). Consequently, when developing innovations, corporate inventors, in an effort to mitigate against errors and losses for their employer, will more likely select search and problem-solving paths as well as technology alternatives that resemble past innovation paths that achieved market acceptance (Corbett and Hmieleski, 2007). In other words, in the process of development of original ideas distant to their employer's knowledge base, corporate inventors may see the idea mold to the market objectives and assets of their employer.

Independent inventors, on the other hand, may have a higher degree of autonomy over their activity, are often found to be more generalist on the problem-solving methods they use (Corbett and Hmieleski, 2007), and are more likely to experiment with new search and problem-solving paths or undertake more risky development paths (Markman et al., 2002; Dahlin et al., 2004; Lettl et al., 2009). Less constrained by an organizationally restricted set of valuable technological problems, independent inventors may be more likely to explore technological solutions to problems that appear to have low market value, and may later co-opt ideas and solutions to completely different uses than the ones envisaged (Felin et al., 2016; von Hippel and von Krogh, 2016). Even if working as consultant in one or in several companies, independent inventors are external to these companies and therefore less prone to inertia towards local search, while at the same time being less able to source firm internal organizational skills and assets (Dahlin et al., 2004; Lettl et al., 2009). They are less knowledgeable about the company organizational structures than corporate inventors and consequently less likely to identify company internal knowledge and resources useful for the development of the innovation and to secure company internal support for their development path. Independent inventors may then have fewer possibilities and incentives to modify the original innovation idea.

In sum, firms' organizational structures provide resources and opportunities, but at the same time their organizational, financial and market rigidities may create disincentives for corporate inventors to pursue exploratory development paths. Hence, corporate inventors may be more likely than independent inventors to focus on the possibility of market return from mainstream customers and as a consequence erode the imprinting effect of knowledge sources on the nature of innovation (Burgelman, 1994; Riggs and von Hippel, 1994; Agarwal et al., 2004). In other words, the nature of innovations developed by corporate inventors may be less likely to depend on the imprinting effect of original ideas than the nature of innovations developed by independent inventors. Hence, we hypothesize:

> *H2: The imprinting effect of ideas on innovative outcome will be weaker for corporate inventors than for inventors without corporate employment (independent/self-employed).*

We further need to note that firms are not all equal in their resources and innovative skills, and some are more conducive to creativity and innovation (Amabile, 1988; O'Connor and De Martino, 2006). Technological leader and follower firms develop organizational, market and technological routines and resources, which lead them to pursue different innovation strategies (Lieberman and Montgomery, 1988; Dos Santos and Peffers, 1995; Giachetti et al., 2017). These, in turn, may influence the possibilities of corporate inventors to engage in certain type of heuristics and problem-solving paths rather than others (Amabile, 1988; Dahlin et al., 2004; Lettl et al., 2009; O'Connor and De Martino, 2006).

Being amongst the first to commercialize new technologies and products, technology leaders often outperform followers because their technological leadership provides positive economic benefits and learning advances, which lead to lower average costs and enables them to win patent or R&D races (Lieberman and Montgomery, 1988). Due to the technological leadership and market competences they invest in, leaders are better placed to identify opportunities that apply their pre-existent knowledge and to recombine existing technologies into new applications (Cattani, 2006; Ching, 2016). They will build resilience to unexpected technological, market and institutional challenges (Marquis and Huang, 2010; Ching, 2016), as new uses and functions seem to result mostly from factors endogenous to the technology and the contexts to which the technology is exposed (Andriani et al., 2017). In this environment, inventors, in the process of innovation development, are able to access resources and are exposed to routines that encourage them to explore new applications and hence to mold initial ideas to fit unexpected or foresighted challenges. In other words, existing selective routines and resources in technology leader firms might erode, or mold, the original ideas of inventors' projects.

Technology followers by definition bring new products and technologies to the market after leaders have already done so.[3] While eventually getting lower marginal profits, technology followers face lower technological and market uncertainty because they can use technological and market information on the leaders' products to develop their own. In addition, being "skilled at imitating acting as connectors between the innovators and the masses" (Chang and Harrington, 2007, p. 648), follower firms are less constrained than leaders by the "not invented here" syndrome and consequently more efficient in nurturing ideas in a way that best fits new market developments (Katz and Allen, 1982; Cohen and Levinthal, 1990).

However, replication and imitation is not a simple and effortless process (Winter and Szulanski, 2001; D'Adderio, 2014). Followers' R&D activities may need to focus more on customization of the originally externally developed technology to the needs of specific markets, on problem-solving associated with product design and production of specific product attributes, on streamlining processes, and on reducing costs (D'Adderio, 2014). Having built specific technological capabilities and market foresight and monitoring routines tuned for re-adaptation and replication, i.e. for developing new products based on leaders' initial launches (Winter and Szulanski, 2001; D'Adderio, 2014), follower firms may be less pre-adapted to create and explore opportunities for technological speciation and exaptation (Dew et al., 2004; Cattani, 2006). Hence, in followers firms, inventors may find a development environment, where resources and selective practices permit the original ideas of their projects to be relatively more reinforced than is the case for leaders.

In sum, the technological pioneering objectives as well as their market risk-taking attitude make technological leader firms an environment where the imprinting effect of the original idea is eroded. Instead, technological follower firms with their technological and market objectives focused on innovating around original launches make them an environment that is less likely to moderate the imprinting effect of the original idea. Hence, we hypothesize that:

> *H3: The imprinting effect of ideas on innovative outcome will be stronger in technology followers than in technology leaders.*

Data

The data to examine our hypotheses empirically comes from the PIEMINV survey, an original survey of industrial inventors in Piedmont (a region in Northern Italy). The survey questionnaire was sent to the population of inventors named on at least one European Patent Office (EPO) patent during the period 1998-2005 and with an inventor address in Piedmont (3,922 patents and 3,027 inventors were identified). The patent application data comes from Patstat via the EP-INV database produced by ICRIOS-Bocconi. After cleaning and confirming address data and excluding inventors working at universities and at public research organizations we sent out 2,916 questionnaires by email and post between autumn 2009 and spring 2010. We obtained 938 valid responses (31% response rate).

The questionnaire was designed to investigate various aspects of the innovation activities of inventors in Piedmont, such as its outcomes and the university's contribution to the innovation process. The survey was targeted at inventors who participate directly in the development processes of individual innovations rather than managers, who are usually the target of innovation surveys. The survey thus has the benefit of being able to provide insights into the processes behind specific innovations.

The survey was constituted of four sections. For this paper we rely mostly on data collected in section four of the survey, where respondents were asked to reflect and report on the process behind two of their inventions[4] (1) the invention with the highest contribution from university knowledge, and (2) the invention with the highest economic impact. We do not use a standardized measure to identify inventions belonging to one or the other group but instead ask inventors to select their inventions that best fit either category. In doing so, we also allow inventors to name the same invention twice as the invention with the highest contribution from university knowledge can also be the one that achieved highest economic impact.[5] Section 4 of the survey was completed by 173 inventors reporting on 262 inventions. This includes inventors who only report to have one invention or innovation. Of the reported inventions, 109 were named as having the highest contribution from universities, 94 as having highest economic impact and 59 were named as both of highest economic impact and with the highest contribution from universities. While not being limited to patented outcomes, respondents in the majority of cases do refer to an invention that was patented or for which a patent application was filed.

Considering the innovation processes behind up to two inventions by the same inventor allows overcoming difficulties of comparing innovative outcomes with different technological and market foci across inventors with different competences and experiences. In other words, it permits us to isolate the effects of original imprint and development environment. In addition, the survey provides information on inventors' characteristics that permit us to control for individual fixed effects that may influence their innovative output (Felin and Hesterly, 2007; Singh and Fleming, 2010).

The questions relating to specific innovation development processes behind two inventions were only addressed to inventors that had reportedly benefitted at least once from university knowledge. This was done in order to have answers relative to both types of inventions, as explained below. We are aware that this may have resulted in having selected the most technologically competent industrial inventors to answer.[6]

It is further important to note, that respondents were not posed questions about their perceptions, were not required to subjectively evaluate situations or performance, and neither asked about their agreement with different statements. Questions instead refer to specific elements of the innovative process that inventors would have direct involvement in. In any case, we test for common method bias in our data using the Harman's single-factor test (Podsakoff et al. 2003). We find three different factors with eigenvalues greater than 1, which overall explain 80% of total variance, suggesting that common method bias is not a concern in our data.

Dependent variables

We create our dependent variables based on survey information about the development behind two specific innovative processes: (1) outcomes with the highest contribution from university knowledge, and (2) outcomes with the highest economic impact.[7] Given that university knowledge is particularly important for solving technological problems during the innovation development process (Cohen et al., 2002), the innovative outcome for which university knowledge was of greatest importance can be considered a good proxy for technologically novel innovations (see for example discussion in Sorensen and Fleming, 2004).[8,9] The outcome with the highest economic impact is used to proxy for market success innovations.[10] We thus create a nominal dependent variable which reports on whether the inventor's activity leads to a) a market success innovation, b) a technologically novel innovation, or c) a technological novel market success innovation. While market success innovations and technologically-novel innovations are not surveyed using the exactly same wording or logic, their inherent logics fit the nature of technologically novel innovations (development of state of the art technological knowledge) and market success innovations (appropriating high market returns) and are in line with prior literature that focused on innovations that could not have developed (without considerable delay) in absence of university contribution and on the market returns of new products that relied on different raw ideas (see for example Mansfield, 1991; Kornish and Ulrich, 2014). In addition, this measurement design permits us to effectively contrast the effect of different knowledge sources and development environments: As we could expect innovations originating from university knowledge to result in technologically novel innovations (Dasgupta and David, 1994; Rosenberg and Nelson, 1994), when this is not the case, the environment may have provided resources, opportunities and incentives to attenuate the imprint of the university origin, *ceteris paribus*.

Independent variables

The first set of independent variables capture information on the process of idea-generation. The survey asked respondents about the origin of the idea leading to the innovative outcomes (respondents could only provide information about the main knowledge source). Based on this information, we build variables that capture information on the most important knowledge source at the origin in correspondence with our framework.[11,12] *Firm R&D* source takes the value 1 if the project had at its origin R&D undertaken by the company lab. *Firm operations* takes the value 1 if the project's original idea was based on operations and market activities of the company, including feedback and requirements from customers, suppliers or consultants. *University* source takes the value 1 if the project's original idea was based on university knowledge, knowledge developed in collaboration with universities, or during the inventor's training (MSc and PhD).

The second set of independent variables captures information on the environment to which inventors were exposed during the processes of innovation-development. The survey asked respondents about their employment situation at the time the innovation was being developed, specifically whether they were employed by an established firm, or were self-employed.[13] Based on this information we create the variable *independent* that takes the value 1 if the inventor was self-employed when developing the innovation.[14]

Additionally, we characterize the development environment of corporate inventors by taking into consideration the firm strategy towards technological leadership. The survey data does not provide us with any information that can be used as a proxy for technological leadership. Hence, we collected information on the patent counts and patent citation counts of the organization to which the inventor was affiliated at the time of the survey. We collected the number of patents filed by the respective companies during the 1998 to 2005 period, regardless of whether they were granted or not, and the number of citations received by these until 2011 from the Derwent Innovations Index (DII). The DII contains information grouped around a patent family, which allows us to uniquely identify the original patent and avoid multiple counts. We then generate a variable for *Leader* that take the value one for those inventors working for a company that is in the top 25 percentile of companies with regard to the number of patent citations in its technological class (Lerner, 1997). The variable *Follower* takes the value 1 for inventors that were not self-employed and worked in a company that is not in the top 25% regarding their patent citations. This measure thus captures quantity and technological importance of patents produced by the firm.[15]

By contrasting the innovative process of inventors exposed to different environments from independent/ self-employed inventor to inventors employed in organizations that were technology leaders or technology followers, we capture environments in which inventors have different degrees of individual freedom, availability of resources, opportunities and skills, and rewards for innovation (Amabile, 1988). Finally, we include the linear interaction between each knowledge source at the origin of the innovation and each development environment in our analysis.

[Table 1]

Table 1 reports the number of respondents by idea source and development environment. After removing observations with missing values in any of the main variables we see that 142 innovations were developed by inventors at *follower* firms, 58 at *leader* firms, and 29 as *independent* inventors. Our data suggests that innovation projects in *leader* and *follower* firms mostly originate from internal *firm R&D* developments rather than *firm operations* or *university knowledge*. *Followers* report slightly more innovations that relied on university sources compared to *followers*. For *Independent* inventors *firm R&D* remains the most likely source, but they also rely more heavily on *firm operations* and *university knowledge* sources compared to established firms. A Fisher's exact test does not reject the null hypothesis of the independence between sources at the origin of the innovation project and environments in our sample. Thus, even if knowledge sources used by inventors may not be completely independent from the environment in which the inventor generates the idea, among the best ideas that are further pursed and developed by the inventor this association is no longer found.

Control variables

Our research design permits us to account to some extent for individuals fixed effects by considering up to two innovations from each inventor. In addition, we control for other factors that have been shown to influence inventors' search process and productivity such as the characteristics of inventors (personal traits and their background) and the institutional facilitators that influence the attention and interest of inventors towards specific puzzles, knowledge sources, and heuristics (Amabile, 1988; Markman et al., 2002; Dahlin, Taylor, and Fichman, 2004; Lettl et al., 2009; Azoulay et al., 2011).

To account for the inventor's experience, we followed prior literature and include the number of patent applications, in our case the number of EPO patent applications he or she filed between 1998 and 2005. We also include age in 2010 (the time of the survey). We proxy the diversity of inventors' external network using their mobility experience and include a mobility measure that takes the value of 1 for inventors that had changed employers at least once since completion of their training or that had spent more than six months outside Piedmont as part of their work[16]. Furthermore, we control for whether the inventor has a university degree, and for their gender.

We further include the most common technology class of patents filed by each of the inventors in our analysis. We identify three technology classes, the most common being electronics/instruments with 42% of inventors followed by machinery/others with 35% and chemistry/pharmaceuticals with 12%.[17]

The sources of project development financing could also influence the development efforts and the criteria to select preliminary results during the development process. The survey enquired about the following forms of financing: public research funds (public financing), company financing or venture capital (firm financing), or both. While the majority of projects were financed firm internally, 16% of innovations were wholly or partially financed through public research grants. We add a dichotomous variable for public financing and for joint financing.

Table 2 provides a description of all the variables used in this study as well as their means and standard deviations.

[Table 2]

Descriptive Analysis

We first provide a descriptive analysis. Table 3 and Figure 2 report the innovation outcome for different idea sources and development environments.

[Table 3 and Figure 2]

Firm R&D can result in any set of innovations. Figure 2 shows that *independent* inventors when relying on *firm R&D* knowledge sources seem less able to produce innovations with *both technologically-novel and market success* than corporate inventors. Comparing corporate inventors, we find that *firm R&D* knowledge sources used by inventors at *leader* firms are more often associated with *both technologically-*

novel and market success innovations, compared to *followers*, suggesting that leaders are better able to follow exploratory research paths that lead to market success.

University knowledge more often results in the development of *technologically novel innovations*, but, in the case of corporate inventors at *leader* firms, it almost equally as often results in *both technologically-novel and market success* innovations. These results suggest that corporate inventors in *leader* firms follow search and knowledge recombination paths tuned to create technological solutions for a new market need and for adding market relevance in a variety of projects. In other words, the imprinting effect of knowledge sources at the origin of the innovative project seem indeed to be more likely to erode in the innovative processes of inventors at *leader* firms.

Finally, *firm operations* sources lead to market success innovations in 49% of cases. Surprisingly, around 40% of projects originating from *firm operations* by corporate inventors in *leader* and *follower* firms result in *technologically novel innovations* rather than in *both technologically-novel and market success* innovations, as is the case with *independent* inventors. This may provide evidence of the strength of the development environment in moderating the effect of knowledge source imprints on innovation outcomes. In an effort to develop a *both technologically-novel and market success* innovation, corporate inventors may access resources to recombine the original idea in ways that may improve significantly the technology, and envisage different functionalities and applications, eroding more strongly the initial idea than *independent* inventors.

In sum, this analysis based on the descriptive statistics of our sample suggests that knowledge sources at the origin of the innovative process, as well as the environment in which innovation development takes place influence the outcomes of inventors' activities. Still, some individual and project characteristics may concur to explain some of these dynamics. In order to account for these in our analysis, next we report results of the regression analysis in which we control for individual and other project characteristics.

Regression analysis

We run a multinomial logit regression which estimates the probability of each type of innovation outcome as a function of a set of explanatory variables, including the knowledge sources for idea generation and their interaction with the environment in which the innovation was developed. We use cluster standard errors where the clusters are based on the individual inventor. Multinomial logit regressions do not make assumptions about normality, linearity, or homoscedasticity and are well suited to a nominal dependent variable with 3 or more categories. In our model there might be some concern about the overlap between the three categories.[18] Moreover, due to the small number of observations for some of the interaction effects, the magnitudes of effects have to be viewed with caution. The analysis will mostly help to establish if correlations observed in the descriptive analysis hold when other project and individual characteristics are accounted for.

We follow a stepwise strategy in our regression analysis reported in Table 4. First, we report results for the different knowledge sources, ignoring the development environment, to establish a baseline for H1. Model 2 then compares the innovative output of ideas developed by independent inventors directly to those developed by corporate inventors, i.e. inventors that are employees of a company, in order to test individually H2. Third, we focus on the innovative output of ideas developed only by corporate inventors, and compare ideas developed by inventors at *follower* and at *leader* firms in order to test individually H3. Finally, we test simultaneously H1, H2 and H3 in model 4. We do so by comparing the innovative output of ideas developed in the three development environments (independent inventors, corporate inventors employed at follower firms, and corporate inventors employed at leader firms).

In all three models, the development environment and idea source variables enter independent of one another, i.e. one does not compromise the effect of the other. Model 4 confirms results of models 1 to 4 and shall form the basis of our discussion. As we estimate a non-linear model, where the effect of the variables cannot be completely assessed from the size of the coefficients, we compute the predicted probabilities for each innovation outcome. Figure 3 plots the predicted probabilities for model 4.

[Table 4 and Figure 3]

First, we find that *market success* innovations are less likely to result from projects having at their origin *university* knowledge sources compared to *firm R&D* and *firm operations*, thus confirming the descriptive results. Figure 3 further indicates that *firm R&D* can result in any type of innovation, regardless of development environment thus showing a lower level of imprinting than *university* knowledge sources and *firm operations*, which provides partial support for H1.

We then compare individual and corporate inventors in order to test H2. Results (model 2 and 4) and the visual representation of the observed effects in Figure 3 suggest that imprinting from original knowledge sources persist most for *independent* inventors. *Technologically novel* innovations developed by *independent* inventors are more likely to result from projects having at their origin *university knowledge* sources and least likely to result from projects originating from *firm operational* sources. The opposite is found for *market success innovations,* which are more likely to result from *firm operational* sources. Instead, independently of the knowledge source at the origin, projects developed by inventors at companies have an almost constant probability of developing a *technologically novel innovation.* The imprinting effect of the original idea thus does not persist to the same extent. These results provide support for H2, which stated that the imprinting effect of the original idea is weaker for corporate inventors than for *independent* inventors.

In order to test H3 we compare corporate inventors at leader and at follower firms. The results in models 3 and 4 of Table 4 indicate a higher propensity for *market success* for inventors at leader firms. The visual representation of the observed effects in Figure 3 further shows that inventors at *leader* firms have a higher probability to transform *university* ideas into *both technologically-novel and market success* innovations. Similarly, when pursuing ideas from *firm R&D* sources, inventors in *leaders* firms are more likely to develop innovations of *both technology and market relevance*. This suggests that inventors at *leaders* are better able to shape technology based ideas into new market opportunities regardless the idea source, while those at *followers* have proportionate reduced resources to support the use and recombination of university knowledge into new functions, products and technologies targeting new markets, leading inventors to pursue more closely the initial technological problem behind the project.

These results provide some support to H3, which stated that the imprint effect of the original idea is less strong for corporate inventors in *leader* compared to those in *follower* firms.

Control variables are robust across the four models. While insignificant, they point in the expected direction with public financing and higher education showing the highest correlation with *technologically novel* innovations and joint financing with innovations that are *both technologically-novel and market success*. The female dummy also shows a positive sign for *both technologically-novel and market success* innovations compared to the other two types. Mobility, age and patenting experience show no clear relationship to a specific innovation type.

Robustness tests

We perform several robustness checks to test the sensitivity of our results to omitted observations and variables and the operationalization of our independent variables. Results are available in an *Online Supplement*.

Firstly, we estimate a model that adds to our sample 26 innovations that were developed in universities, public research institutes and other non-corporate organizations and that had previously been excluded. This model mainly captures the effect of these environments in the development of some industrial ideas (please see endnote 11). The results confirm the findings of Table 4 and moreover suggest that the imprinting effect of *university* knowledge is weaker for inventors that develop their idea at universities/PROs than for *individual* inventors, as the development of university based ideas into innovations that are *both technologically-novel and market success* is more likely to occur there. The imprinting effect of *firm operations* sources however is as strong as for *independent* inventors and less likely to develop *into technologically novel* innovations.

Second, on the subsample of corporate inventors, we may further be concerned that other firm specific characteristics such as size may explain the effect of development environment on innovation outcomes. However, as our variables *leader* and *follower* are based on the number of citations to patents developed by companies, we do not expect, and neither find, an additional effect for other firm measures. Rerunning our model 3 with variables that capture firm information such as firm size (categories), age (*young*), or being in a provincial capital (*central*) finds no significant effects for any of the measures and strengthens some of our results.

Finally, we recoded the classification of technology *leaders* and *followers*, taking into account the average number of citations per patent rather than the number of citations received by all patents. This leads to a reclassification of 70 out of 233 inventions from *leader* to *follower* firms and vice versa. On average the number of citation per patent are low (mean=0.14) as most patents receive no or very few citations. Rerunning the regressions using this new classification, we no longer find a significant difference between *leader* and *follower* firms, thus indicating that support for H3 depends on the definition of technological leadership. We should however stress that while measuring inventive activity through average number of citations permits to control for firm size effects, it also introduces a bias in that firms that invest in general knowledge development strategies that lacks follow-on development are indistinguishable from those with limited but cited inventive activity. Among other possible explanations, a high number of patents associated with a relative lower average number of citations may be due to signaling to the same or related industries and/or represent technologies that are only relevant for a very small set of products and processes. Further, comparing the coefficients for *leader* between model 4 (Table 4) and the robustness check shows that these are not significantly different, and any observed differences may thus also be driven by the small sample sizes. Still, this result raises questions as to the definition of *leader* and *follower* firms.

Discussion and Conclusions

With the aim of improving existing knowledge on whether the same type of innovation outcome can originate from different development contexts when pursuing similar types of original innovation idea, this study focused on the interaction between *origin* and *development environment* in the process of speciation. Empirically, we use data from a survey of inventors on the process of innovation development of three innovations: market success innovation, technologically novel innovations and innovations that are both technologically novel and market success, and control for different individual and project factors that could influence the innovation process and outcome. Overall results provide evidence on both differentiated degrees of persistence of the imprinting effect for different idea sources, as well as of differentiated effects for different development environments in fostering idea speciation.

Results show that firm operational knowledge is more likely to lead to market success innovations in any development environment. This is in line with research that has shown that the origin of technological knowledge influence innovation output (Phene et al., 2006). Firm R&D knowledge can results in any innovation outcome while unaffected by the development environment. Finally, the imprinting effect from university knowledge is weakest, suggesting that their effect is more likely to erode during development. This provides partial support to H1.

Additionally, results suggest that environments are also not all equal in providing resources and opportunities for moderating imprinting effects of the original knowledge sources. Independent inventors observe a stronger imprinting effect than corporate inventors, and pursue more exploratory search paths. When relying on university knowledge sources independent inventors more often produce technologically novel innovations and when relying on firm operational sources they more often produce innovations of both technological and market success than corporate inventors. In comparison, the imprinting effect of the original idea is less strong among corporate inventors, providing support to H2.

We also found differences for corporate inventors at technology leaders and followers. When compared to inventors at follower firms, inventors at leader firms are more likely to develop innovations that are both technologically novel and market success, especially when relying on university knowledge sources and to a lesser extent firm R&D sources, and about equally likely to produce market success innovations when relying on firm operational sources. This suggests that at technology leader firms the imprinting effect from knowledge sources at the innovation project origin is weaker than at follower firms, providing some support to H3.

Our study makes several contributions. First, it can inform the evolutionary economics literature, which has stressed that organizations develop routines and competences that will influence the incentives for learning and experimentation of their employees and thus the characteristics of their innovation outcomes (Nelson and Winter, 1982; Fleming, 2002; Dosi and Marengo, 2007). This study contributes by showing that the process of search and recombination for innovation development is influenced by the resources and opportunities available to the actors that participate in the process. Specifically, we find that inventors at *leader* firms are more able to produce innovations that are both technologically novel and market success than *followers*. Firms that invest in accumulating knowledge (even without a subsequent application need) may build their luck (Garud et al., 2016) to cope with technological, market or institutional challenges (Cattani, 2006; Marquis and Huang, 2010; Ching, 2016).

Second, our evidence can inform the technological speciation literature, by suggesting that the strength of the 'selection forces' (Cattani, p.286) in guiding inventors' development efforts towards different types of innovative outcomes depend on the type of knowledge sources at the project origin. Specifically, results suggest that the imprinting of ideas based on firms' operational sources, which may be thought as more explicit and closer to the existing technological and market realities of the firm, is more likely to persist than university and firm R&D sources, which may instead reflect more abstract technological and market developments (Riggs and von Hippel, 1994; Cohen et al., 2002).

This research may also inform managers. The positive aspect of our results to innovation and R&D managers is that it might be possible to achieve the innovative targets of the firm by strategically managing inventors' access to specific knowledge sources. In particular, market success innovations are more likely to be achieved through projects that pursue ideas resulting from operational and commercial activities, confirming Zhou et al. (2005). Moreover, ideas from firms' operational activities reveal a greater imprinting effect compared to university or firm internal sources, and firms' ability to appropriate market value from these ideas may therefore largely depend on the speed with which firms are able to bring innovations to the market. This research also suggests that involving independent inventors in the development of ideas resulting from firm operational and commercial activities may leverage possibilities to explore further technological solutions. University ideas are instead those with the weakest imprinting effect, and the output of their development is likely to differ across development environments. Hence, a university idea may lead to different types of innovation, depending on the resources and opportunities available to inventors engaged in its development. Results also indicate that the resources and opportunities for certain development paths will be particularly difficult to be sourced in certain environments. Specifically, our results suggest that managers at follower firms will face greater difficulties than those at leader firms in the development of technologically novel market success.

Research limitations and Future research

This study is not without some limitations mainly associated with the empirical setting and small sample size. Addressing these limitations could open up several avenues for future research. First, our research design that compares two different types of inventions or innovation outcomes as provided by industrial researchers rather than drawing on a sample of innovations in one technological field. While our research design has several advantages in terms of identification of innovation outcomes, and isolation of the individual characteristics (Lourdes Sosa, 2013), further research is needed to examine whether these findings are corroborated when comparing innovation outcomes selected on the basis of other information to evaluate their market return or technological novelty.

Second, we focus on inventors in a single country and region, Piedmont in Italy. Piedmont has a strong manufacturing sector with a particular concentration in automotive and aerospace manufacturing and the processes governing innovation development may be different from those in other regions or sectors. Still, being amongst the strongest regions in Europe with regard to technological and industrial developments make our findings relevant for other industrial regions within Europe. The examination of the generalizability of our results relying on different research methods and addressing different national and regional contexts would provide further insights on this issue.

Third, our study builds on a survey of inventors who were listed on applications to the EPO, which can lead to two forms of biases. Sampling based on patent inventors will exclude some of the most innovative individuals working in sectors or industries that do not produce patents. Further, sampling based on the EPO will favor inventors at larger companies with the necessary resources required for the costly patenting process. Regardless, inventors are considered as one of the most important groups of workers in technology and product development, and patents and inventor surveys have been one of the main means to explore innovation processes.

Fourth, we identify technology leader firms and technology follower firms based on the total number of citations to firms patents. However, we need to stress that in Europe the majority of citations are added by patent officers rather than inventors or firms (Nagaoka et al., 2010), which blurs the possibility that one captures “quality or importance” of inventive output through citations. In fact, a robustness check relying on average citation numbers finds no longer any significant differences between the two contexts. Future research using other measures to identify leader and follower firms is thus needed to validate our findings.

Finally, information on the idea generation and development process of these innovations is limited to the questions posed on the questionnaire. Specifically, innovations may be informed by more than one knowledge source and its development may take it across more than one development setting. The small dataset also does not allow us to develop more fine-grained classifications or typologies and future research is needed to examine these issues. In addition, our research design was quantitative, and this prevents us from more in-depth insights on the process of developing innovations. Qualitative research based on interviews and case studies could also help provide rich insights on the development environment and knowledge sources of the different innovations, as well as the dynamic in knowledge sources in idea generation and during innovation development. In particular, more insights could be obtained on the specificity of the idea speciation process, if it occurred through adaptation or exaptation. In this study, we cannot say much about whether external knowledge sources are used differently by inventors in leader and in follower firms in the process of innovation development, nor whether these firms select their inventors differently. Our data also does not allow us to say much about whether expectations about a certain type of innovation outcome influence the inventor’s choice of a specific development path for the original idea. Future qualitative research could also provide insights on the form in which external knowledge sources are accessed and used in different environments, on the specific routines for building and managing creative teams, for recruiting inventors, as well as for selecting ideas and technological paths.

In conclusion, our study was a first attempt to study whether and how the nature of innovations is influenced by the knowledge sources feeding the idea-generation process and how their imprints interact with the development environment in which the inventor carries out the project.

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Figures

Figure 1 – Framework for analysis

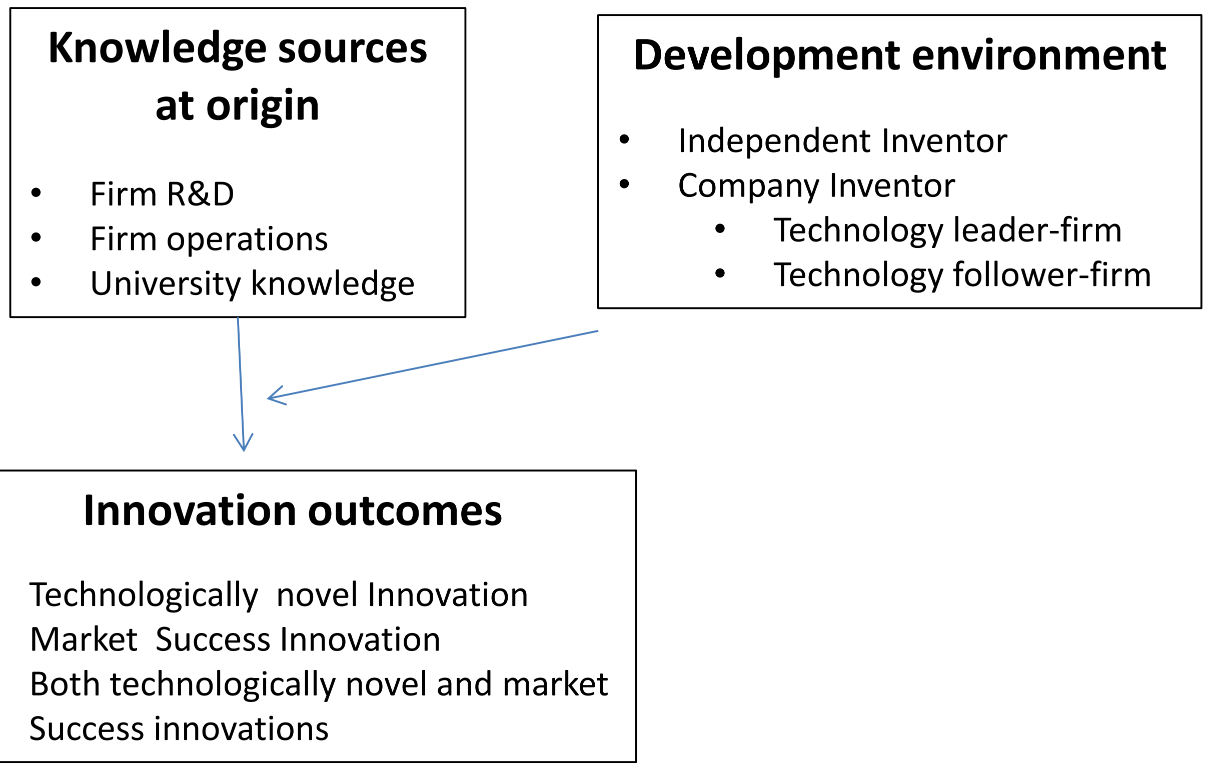


Figure 2 Innovation outcomes by idea source and development environment (as share of all outcomes)

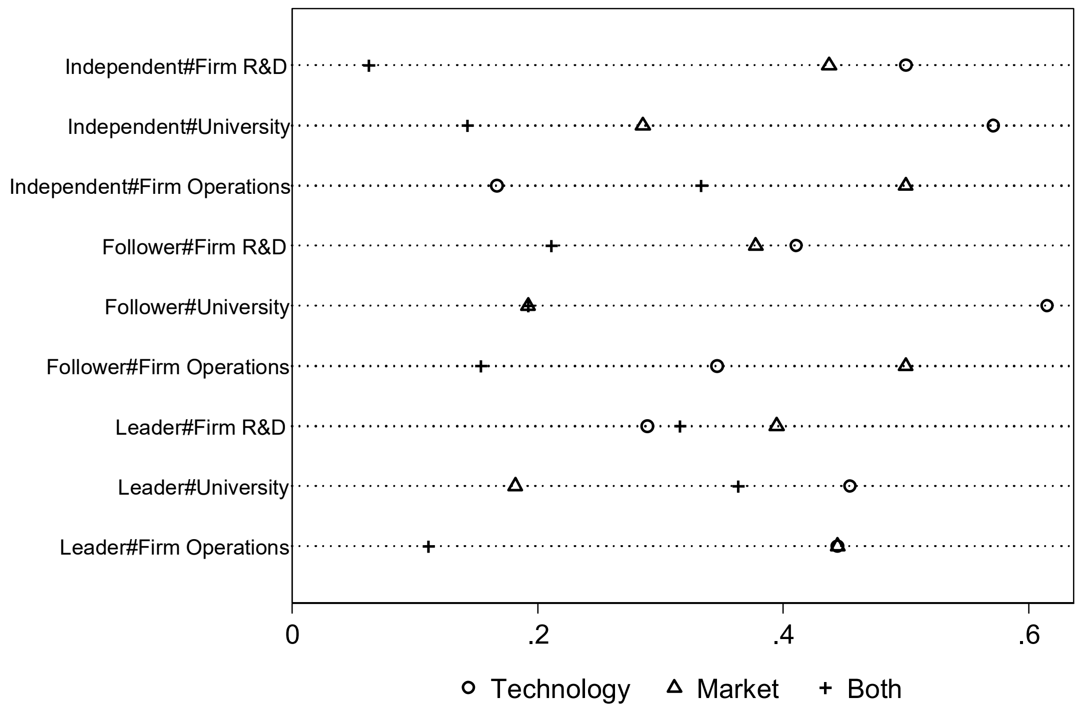
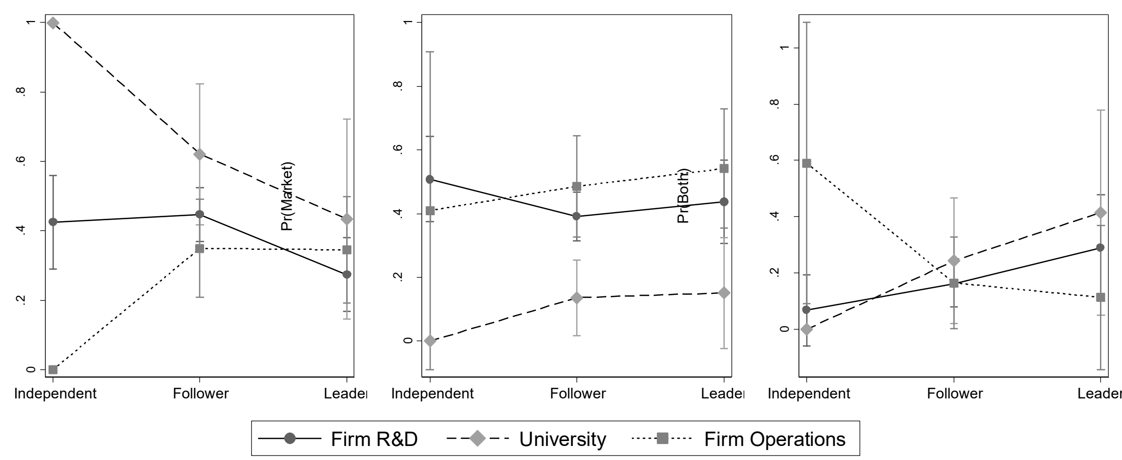


Figure 3: Predicted probabilities by idea source and development environment for each innovation outcome



Note: 95% confidence intervals are reported. Confidence intervals are zero where observations are completely determined.

Tables

Table 1: Idea sources by development environment (# and % of respondents)

Idea Source	Firm R&D	Firm Operations	University	Total
Environment				
Independent inventors	16 (55%)	6 (21%)	7 (24%)	**29**
Corporate inventors	128 (64%)	35 (18%)	37 (19%)	**200**
Follower firm	90 (63%)	26 (18%)	26 (18%)	**142**
Leader firm	38 (66%)	9 (16%)	11 (19%)	**58**
Total	**144**	**41**	**44**	**229**

Note: Exclusive of innovations that were developed in PROs or due to serendipitous association. Fisher's exact test: p=0.870; Pearson chi2: p= 0.895

Table 2: Descriptive Statistics and Variable Description

Variable	Description	mean	sd	min	max
Innovation Outcome	*Source: Survey*				
Technologically novel	Innovation with the highest contribution from university knowledge	0.41	0.49	0	1
Market Success	Innovation with the greatest market value	0.37	0.48	0	1
Both	Innovation with the highest contribution from university knowledge, that is also of greatest market value	0.21	0.41	0	1
Idea Sources	*Source: Survey*				
Firm R&D	Innovation that had firm internal R&D activities at its origin	0.63	0.48	0	1
University knowledge	Innovation that had university knowledge at its origin	0.19	0.39	0	1
Firm operations	Innovation that had firm operational or commercial activities at its origin	0.18	0.38	0	1
Development Environment	*Source: Survey + Derwent Innovations Index*				
Independent	Innovation developed by independent/self-employed inventor	0.13	0.33	0	1
Follower firm	Innovation developed in firms that are in the lower 75 percent regarding their citations in the 1998-2005 period	0.62	0.49	0	1
Leader firm	Innovation developed in firms that are in the upper 25 percent regarding their citations in the 1998-2005 period	0.25	0.44	0	1
Controls	*Source: Survey + Derwent Innovations Index*				
Firm financing	Innovation development was solely financed by the firm	0.84	0.27	0	1
Public financing	Innovation development was solely financed by public funds	0.08	0.36	0	1
Joint financing	Innovation development was jointly funded through firm internal and public funds.	0.08	0.27	0	1
Age	Age of the inventor in 2009/10	47.93	10.05	31	88
Higher education	Inventor with a university degree	0.81	0.39	0	1
Female	Gender of the inventor	0.12	0.33	0	1
Mobile	Inventor who has worked for more than one company and/or has spent at least 6 months outside Piedmont	0.72	0.45	0	1
Patent number 98-05	Number of patent applications assigned to the inventor during the 1998-2005 period	2.80	3.37	1	24
Chemistry and pharmaceuticals	The majority of the inventor's patents are in this technology area	0.12	0.33	0	1
Machinery and process eng.		0.35	0.48	0	1
Electronics and instruments		0.41	0.49	0	1

Table 3: Idea sources and development environment for different types of innovation outcomes (% of respondents)

	Technologically novel	Market Success	Both Technologically-novel and Market Success	Total (# respondents)
Idea sources				
Firm R&D	38.89	38.89	22.22	**144**
University	56.82	20.45	22.73	**44**
Firm Operations	34.15	48.78	17.07	**41**
Development Environment				
Independent	44.83	41.38	13.79	**29**
Corporate Inventor	41.00	36.50	22.50	**200**
Follower firm	43.66	36.62	19.72	**142**
Leader firm	34.48	36.21	29.31	**58**
Total (# respondents)	**95**	**85**	**49**	**229**

Note: Exclusive of innovations that were developed in PROs or due to serendipitous association.

Table 4: Multinomial logit regression of market success innovations (M), and innovations of both market *and* technology significance (B) compared to the base category (Technologically-novel (T) or market success innovations (M)). Stepwise multinomial logit regression.

	Model 1			Model 2			Model 3			Model 4		
VARIABLES	M | T	B | T	B | M	M | T	B | T	B | M	M | T	B | T	B | M	M | T	B | T	B | M
				Corporate inventor [base]			Follower [base]			Follower [base]		
Leader							0.518*	0.961	0.443	0.600**	1.070*	0.469
							[0.281]	[0.597]	[0.576]	[0.281]	[0.607]	[0.585]
Independent				0.146	-1.145	-1.291				0.312	-0.823	-1.135
				[0.310]	[1.091]	[1.072]				[0.318]	[1.104]	[1.086]
Firm R&D [base]												
University	-1.560***	0.045	1.605**	-1.393***	0.089	1.482**	-1.371**	0.026	1.398*	-1.386**	0.078	1.464*
	[0.451]	[0.536]	[0.663]	[0.448]	[0.537]	[0.651]	[0.574]	[0.650]	[0.816]	[0.560]	[0.684]	[0.828]
Firm Operations	0.378	0.243	-0.136	0.321	-0.130	-0.451	0.426	0.204	-0.222	0.462	0.266	-0.196
	[0.302]	[0.539]	[0.533]	[0.310]	[0.602]	[0.605]	[0.413]	[0.704]	[0.704]	[0.411]	[0.709]	[0.706]
Leader#University							-0.032	0.063	0.096	-0.138	-0.177	-0.039
							[0.896]	[1.097]	[1.241]	[0.887]	[1.132]	[1.315]
Leader#Firm Operations							-0.437	-1.147	-0.710	-0.480	-1.434	-0.955
							[0.576]	[1.643]	[1.609]	[0.564]	[1.643]	[1.612]
Independent#University				-13.786***	-13.103***	0.682				-14.520***	-13.828***	0.693
				[0.819]	[1.321]	[1.175]				[0.903]	[1.391]	[1.295]
Independent#Firm Operations				13.720***	16.613***	2.893*				14.225***	16.807***	2.582
				[0.998]	[1.587]	[1.676]				[1.049]	[1.646]	[1.735]
Public Financing	-0.083	-0.198	-0.115	-0.102	-0.309	-0.207	-0.118	-0.470	-0.352	-0.141	-0.404	-0.262
	[0.362]	[0.763]	[0.870]	[0.362]	[0.761]	[0.865]	[0.352]	[0.844]	[0.896]	[0.350]	[0.846]	[0.906]
Joint Financing	0.314	0.774	0.460	0.312	0.656	0.344	0.181	0.734	0.553	0.456	0.946	0.490
	[0.537]	[1.056]	[1.111]	[0.533]	[1.049]	[1.120]	[0.590]	[1.192]	[1.168]	[0.586]	[1.166]	[1.166]
Age	-0.010	-0.012	-0.002	-0.010	-0.008	0.002	-0.007	0.003	0.011	-0.011	-0.007	0.004
	[0.010]	[0.028]	[0.027]	[0.009]	[0.028]	[0.028]	[0.010]	[0.029]	[0.028]	[0.010]	[0.031]	[0.030]
Higher Education	-0.216	-0.579	-0.363	-0.195	-0.700	-0.505	-0.234	-0.799	-0.565	-0.221	-0.715	-0.494
	[0.216]	[0.565]	[0.561]	[0.211]	[0.588]	[0.589]	[0.243]	[0.617]	[0.594]	[0.217]	[0.592]	[0.581]
Female	-0.297	0.726	1.022	-0.337	0.491	0.828	-0.176	0.173	0.350	-0.308	0.630	0.938
	[0.213]	[0.604]	[0.642]	[0.220]	[0.656]	[0.692]	[0.229]	[0.748]	[0.794]	[0.229]	[0.677]	[0.721]
Mobile	-0.069	-0.081	-0.012	-0.058	-0.049	0.010	-0.021	-0.016	0.005	-0.035	-0.010	0.025
	[0.160]	[0.441]	[0.455]	[0.159]	[0.446]	[0.466]	[0.169]	[0.457]	[0.478]	[0.162]	[0.459]	[0.472]
Patent number	0.003	-0.043	-0.046	0.010	-0.033	-0.043	-0.004	-0.048	-0.044	-0.006	-0.057	-0.051
	[0.018]	[0.070]	[0.071]	[0.016]	[0.070]	[0.071]	[0.017]	[0.062]	[0.065]	[0.017]	[0.067]	[0.069]
Constant	0.514	-0.265	-0.778	0.337	-0.286	-0.624	0.375	-2.059	-2.434	0.162	-0.934	-1.096
	[0.901]	[2.385]	[2.268]	[0.870]	[2.435]	[2.336]	[0.977]	[2.883]	[2.759]	[0.992]	[2.656]	[2.478]
Num. of Observations	199			199			179			199		
Number of Clusters	131			131			118			131		
log Likelihood	-200.2			-196.3			-180.9			-194.0		
Pseudo R Squared	0.052			0.070			0.051			0.081		

Note: Base category in second place (after |); Technology class dummies included in all models; Clustered, robust standard errors in brackets; *** p<0.01, ** p<0.05, * p<0.1

Online Supplement Table S1: Multinomial logit regression of market success innovations (M), and innovations of both market *and* technology significance (B) compared to the base category (Technologically-novel (T) or market success innovations (M)). Robustness checks.

	Univ/PRO included			Firm controls			Alternative leader		
VARIABLES	M | T	B | T	B | M	M | T	B | T	B | M	M | T	B | T	B | M
Follower [base]									
Leader	0.516*	1.090*	0.574	0.660*	2.069**	1.410*	0.194	-0.205	-0.400
	[0.271]	[0.587]	[0.574]	[0.346]	[0.839]	[0.811]	[0.282]	[0.629]	[0.645]
Independent	0.349	-0.813	-1.162				0.218	-1.299	-1.517
	[0.317]	[1.080]	[1.094]				[0.312]	[1.081]	[1.066]
Univ/Pro	0.996	1.622	0.626						
	[1.258]	[1.600]	[1.176]						
Firm R&D [base]									
University	-1.392**	0.044	1.436*	-1.316**	0.406	1.722**	-1.510**	0.711	2.222**
	[0.564]	[0.702]	[0.831]	[0.595]	[0.680]	[0.754]	[0.652]	[0.653]	[0.867]
Firm Operations	0.433	0.286	-0.147	0.514	0.444	-0.069	0.173	0.216	0.043
	[0.410]	[0.705]	[0.700]	[0.465]	[0.770]	[0.722]	[0.381]	[0.669]	[0.679]
Leader#University	-0.040	-0.251	-0.211	-0.294	-0.312	-0.018	0.153	-1.433	-1.586
	[0.891]	[1.114]	[1.305]	[0.917]	[1.186]	[1.185]	[0.876]	[1.223]	[1.399]
Leader#Firm Operations	-0.379	-1.497	-1.118	-0.464	-1.152	-0.689	0.367	-14.847***	-15.214***
	[0.552]	[1.575]	[1.550]	[0.617]	[1.676]	[1.626]	[0.644]	[0.989]	[0.968]
Independent#University	-14.849***	-14.199***	0.650				-15.278***	-15.226***	0.052
	[0.913]	[1.368]	[1.294]				[0.942]	[1.363]	[1.298]
Independent#Firm Operations	14.344***	16.847***	2.504				15.413***	17.760***	2.347
	[1.126]	[1.513]	[1.707]				[1.021]	[1.559]	[1.636]
Univ/PRO#University	-0.591	-0.255	0.337						
	[1.499]	[1.748]	[1.452]						
Univ/PRO#Firm Operations	13.828***	13.524***	-0.304						
	[1.567]	[2.268]	[2.002]						
Young firm				0.341	0.281	-0.060			
				[0.277]	[0.659]	[0.664]			
Central firm				-0.023	1.030	1.054			
				[0.323]	[0.827]	[0.851]			
50 - 250 employees				0.019	-0.557	-0.576			
				[0.322]	[0.875]	[0.915]			
250 – 1000 employees				0.013	-1.819*	-1.831*			
				[0.334]	[1.043]	[1.111]			
>1000 employees				0.234	-0.352	-0.586			
				[0.352]	[0.871]	[0.912]			
Num. of Observations	225			178			199		
Number of Clusters	148			117			131		
log Likelihood	-217.2			-173.2			-191.6		
Pseudo R Squared	0.097			0.0844			0.0926		

Note: Base category in second place (after |); Clustered, robust standard errors in brackets; a constant and all controls are included in the models; *** p<0.01, ** p<0.05, * p<0.1

Footnotes

[1] For example, the technology regimes literature has shown that certain types of innovation may be more likely in some industries than others as firms in different industries engage in the development and use of different technologies and face different types of competition in both the input and output markets (Lee and Malerba, 2017). Similarly, the technological speciation literature provided evidence on how firms pre-adapted firms may be able to develop new technologies through adaptation or exaptation of an existing technology to new technology or market domains with different customer needs and market competition, and consequently with context-specific resource allocation criteria (Levinthal, 1998; Cattani, 2006, Felin et al., 2016).

[2] Imprinting literature has then provided evidence on how capabilities developed as adaptive responses to specific early conditions may later be found useful to respond to specific market or technological challenges (Marquis and Huang, 2010; Ching et al., 2016).

[3] Still, it has been shown that in some situations leaders can imitate the followers (Chang and Harrigton, 2007).

[4] The questionnaire was circulated in Italian. The wording used could be understood by the engineers as invention or innovation. It was made explicit that these did not have to have been patented. For more information see also Fassio et al. (2019).

[5] The alternative use of a standardized measure for technological novel and market success would not be without problems. Firstly, we would need to considerably narrow the technological focus of the innovation and define criteria for identifying innovations and for sampling them. Secondly, it would have been difficult to sample both types of innovations for each inventor using such criteria, likely resulting in final sample of innovations from a small subset of productive inventors.

[6] A detailed non-response bias analysis shows that respondents and non-respondents are similar on observable characteristics such as gender, number of granted patents, forward and backwards citations. We find a small bias for number of patent applications which suggests that non-respondents apply for slightly fewer patents than respondents (Kolmogorov–Smirnov equality-of-distributions test, D=0.07). The only major difference is a higher response rate amongst inventors in electronics and instruments (39%). In addition we check the characteristics of the sub-sample that supplied information on two inventions. They do not differ significantly in terms of gender or patent characteristics from the sample of respondents that did not name two inventions or from the full sample of Piedmont

inventors. However, in a regression model we find that these inventors are higher educated and have produced patents of wider applicability than other respondents (generality index, Trajtenberg, Henderson, and Jaffe, 1997). We thus look at the most technologically competent inventors.

[7] There is a possibility that different inventors may be referring to the same invention, however, only 18 respondents to section four of the survey are co-inventors on at least one of their EPO patents during the 1998 to 2005 period. To further investigate this issue, we went back to the set of innovations with the highest technology value for which a patent number was provided by the respondents and found three occasions where the same innovation was mentioned as technologically novel by two inventors. Overall, any overlap in describing the same innovation more than once will be minimal.

[8] We use this information relative to the development of "inventions for which university knowledge was of greatest importance" as a proxy for the development of technological novel innovations, even through there is the possibility that some technologically novel only outcomes may not have been directly used in the development of new commercialized products or processes. This is because the outcomes were reported by industrial engineers, who seem to understand inventions as outcomes that were patented (most respondents reported inventions that were patented or for which a patent was filed) and commercialized (more than one third of the technological novel innovations were also their market success). Further, a definition of innovation was provided to respondents in the survey.

[9] The quality (or technological value) of patents is normally proxied using patent citation measures (e.g. Trajtenberg et al. 1997) and previous research has found that higher quality patents cite more and are cited more (e.g. Czarnitzki Hussinger, and Schneider, 2012). We check if this is true for our data by using information on the patent number that has been provided by respondents in cases where the innovation had been patented. We were able to identify the specific EPO filed patents associated with technologically novel innovations for 114 inventors. These EPO patents received on average 1.27 citations in the first 5 years following publication and 2.55 citations in total and cited 5.46 patents themselves. These numbers are significantly higher than those observed on average for the same inventors (1.59 forward and 4.39 backward citations) or the total sample of inventors (1.78 forward and 4.85 backward citations). These citation counts are also higher than those on average observed for European patents (0.79 forward and 5.14 backward citations; Squicciarini et al., 2012) suggesting that they are a good measure for technologically novel innovations.

[10] Czarnitzki et al. (2012) argue that the higher 5-year citation rate of academic patents owned by private firms, reflects their higher immediate financial returns and can be considered an indicator for market exploitation. We check if this is the case in our data by comparing the number of forward citations received by technologically novel market success innovations to those that are only technologically novel. We indeed find that the market success innovations receive more citations during the first 5 years than non-market success innovations (1.97 vs. 0.91, ρ<0.05), suggesting their greater market value.

[11] While innovations may be informed by more than one knowledge source, the variety of knowledge sources that individuals and firms use during the innovative process tend to be associated to their resources for engaging in deep or broad search (Laursen and Salter, 2006). By limiting knowledge source at the origin to one main source, we are, to a certain extent, guaranteeing independence between our measures of origin and those on the development environment.

[12] We deleted from the sample five cases in which the inventors reported serendipity as knowledge source, as there were not enough cases to examine interaction with the development environment.

[13] The respondents could moreover select universities, PROs or other non-private sector establishments. Estimations including the 26 projects developed in universities or PROs are reported in Supplementary Table S1. These observations were not included in the main analysis, as the survey was only addressed to industrial inventors and the few industrial inventors reported to have developed ideas in universities or PRO are unlikely to be representative of university inventors.

[14] The survey question asked about the place of work during the development of the invention and respondents selected “private company” or “self-employed professional”. Still, in Italy some companies also employ workers on precarious temporary contracts, and hence it may be possible that some independent/self-employed inventors are doing the same job as corporate employees. These contracts tend to target young (as part of their probation period) or are chosen by very senior individuals (for tax benefits) and by law cannot last or be renewed for more than four years. In any case, whether being senior external consultants or precarious employees these individuals tend to be considered external or temporary to the company, i.e. they can be assumed to feel independent from the organization where they work.

[15] This technology leadership measure come with some caveats. First, the firm at the time at which the survey was undertaken is not necessarily the same firm at which the innovation was developed. However, for the 127 respondents where we were able to identify the specific patent associated with technologically novel innovations the current employer represents the employer at the time of innovation. Second, the measure is correlated with company size. This correlation is intended as large innovative firms are expected to be the ones that stimulate the innovative activity in the region, especially in a manufacturing region such as Piedmont. While small firms can produce patents that are innovative it is still unlikely that they become technology leaders.

[16] Results do not change if we consider both mobility measures separately.

[17] Patents were classified according to the DT7/OST reclassification of IPC (OST, 2004) and then merged into three categories as some of the classes were not or rarely found in the data.

[18] Multinomial logit regressions are generally used to model choices. In our case, inventors do not strictly choose to develop a certain type of innovation, and the innovation outcome is not predetermined. However, the inventor makes a choice regarding which innovation to report upon, a choice that would change with a larger pool of innovations. Further, the outcome category "both", while referring to a very specific category of innovation, might be considered to violate the assumptions of the model. We thus perform a Wald test of combing alternatives in order to determine whether certain categories can be collapsed. In our final model this is rejected for all pairs of outcome categories with the exception of market and both, partially due to the low number of observations within that second group.